

AN INVESTIGATION ON THERMO-HYDRAULIC PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGER WITH RECYCLES

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ABSTRACT

Heat transfer augmentation in heat exchangers has been a key research area in recent times. Over the years, many methods were proposed for heat transfer enhancement such as providing fins, ribs, and twisted tape inserts, etc. In addition to the above-mentioned techniques, utilization of recycles was proposed by few authors and it was demonstrated that this method could effectively increase the heat transfer rate. Several theoretical research were conducted to investigate the effect of recycles on heat transfer rate. However, most of these works are limited to parallel flow heat exchangers and very few works are related to cross-flow heat exchangers. This method of augmentation of heat transfer can be extended to shell and tube heat exchangers as these kinds of heat exchangers are widely used in industries. There is a need to establish a theoretical model to study the thermo-hydraulic performance of shell and tube heat exchanger with recycling. The present work is aimed at developing a theoretical model and hence to do the parametric study on the performance of shell and tube heat exchanger with recycles.

KEYWORDS: Shell and Tube Heat Exchanger, Internal and External Recycling, Length and Area of Heat Exchanger

NOMENCLATURE

- Inlet temperature at tube inlet, T_1
- Outlet temperature at tube side outlet without recycling (normal heat exchanger), T_2
- Outlet temperature at tube side outlet with recycle, T_3
- A Temperature at tube inlet when external recycle is done, T_{21}
- The Temperature at shell side inlet, S_1
- A Temperature at shell side outlet before external recycle is done, S_2
- Final outlet temperature after external recycle is done, S_3

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INTRODUCTION

Heat exchangers are widely used in most industries, in particular, chemical and process industries. Heat Exchanger, as the name implies, transfers heat between two different fluids, phases, etc. which are at two different

temperatures. In practice, no equipment gives 100% efficiency, those losses are very thinkable subject for industries and they are equally dependent on resources like money, working factors, labor considerations, etc. If modern research could decrease the loss percent, it directly improves the profit percent and other factors of a plant. Now the world is in a position of recycling sewage water and use it for the non-cooking purpose; why can't use the same recycling concept in the industry for improving efficiency? A significant amount of research is being done by engineers/scientists and almost every innovation plays its role in industries. In the present investigation, recycling concept is introduced to get improvement in efficiency and heat transfer rate in a shell and tube heat exchanger. The analysis is done on ANSYS workbench 19.0. If this method is able to save installation space then industries get benefitted. By using single pass shell and tube heat exchanger with counterflow, the output temperatures are simulated.

LITERATURE OVERVIEW

To design any heat exchanger, there is some basic design configuration. This configured design gives output with good heat transfer rate efficiency. Significant research has been done on heat exchanger size and design optimization in different methods, different baffle sizes and positions. Nanofluids are used to enhance the heat exchanging process. Caputo et al. (2006) [1] has reported useful information relating to heat exchanger design based on economic optimization. Chii-Dong Ho, 2015 [2] calculated the recycle effect on double pass heat exchangers using asymmetric isotherm conditions with some mathematical equations and got improved outputs. While making any corrections to any heat exchanger, the basic methodology is not allowed to get disturbed and must satisfy all its international standards. Copper oxide (CuO) nanoparticle is found to provide a significant improvement in the total annual cost and other parameters [Hassan Hajabdollahi, 2017] [3]. Fins are used for improved heat transfer rate [Kim, 2010] [4]. To get high heat transfer coefficient hexagonal vent baffles are developed and results clearly indicated higher efficiency, which is found to be higher than the efficiency of trefoil hole baffles [Vijay Teja and Narasimha Rao, 2017] [5]. Theoretical mathematical models are developed and applied to cross flow and parallel flow heat exchangers, and recycling of fluid improved heat transfer rate than normal heat exchanger [Luo, 2017] [6] and Yonghua Youa, 2013 [7].

DESIGN SPECIFICATIONS

The following aspects are considered while designing the heat exchanger:

- When heat is being lost from the heat exchangers, industries get a huge amount of losses in terms of efficiency of plant and profits of the plant. To make up that lost heat, some more heat needs to be added by using some external energy which leads to losses.
- In this research, efforts are placing to reduce the heat loss and improve the heat transferring rate 'Q' and may decrease the total length of the heat exchanger.
- If research can bring down the lost heat, industries will get good output with low heat inputs so that efficiency and profits of the plant will increase. The simple shell and tube heat exchanger is designed.

The following values have been taken to design heat exchanger for ANSYS simulation:

Length of the shell: 2827 mm

Inner diameter of the shells: 1000 mm

Number of tubes: 19

Tubes inner diameter: 38 mm

Tubes outer diameter: 40 mm

Length of the tubes : 3000 mm

External tube diameter: 80 mm

Velocity of flow at both shell and tube side: 4 m/s

Pressure inlet: 2.5 bar

Tube material: Copper

Shell material: Stainless steel

External tube material: Stainless steel

Total length of heat exchanger: 3300 mm

Figures 1, 2 and 3 shown below represent the shell and tube heat exchanger with the external tube. The first figure is nurtured with all components of the heat exchanger. In the second figure, the shell is hidden and tubes of the heat exchanger are shown. In figure 3, side view of the heat exchanger is depicted for the clearer view of inner diameters of tubes.

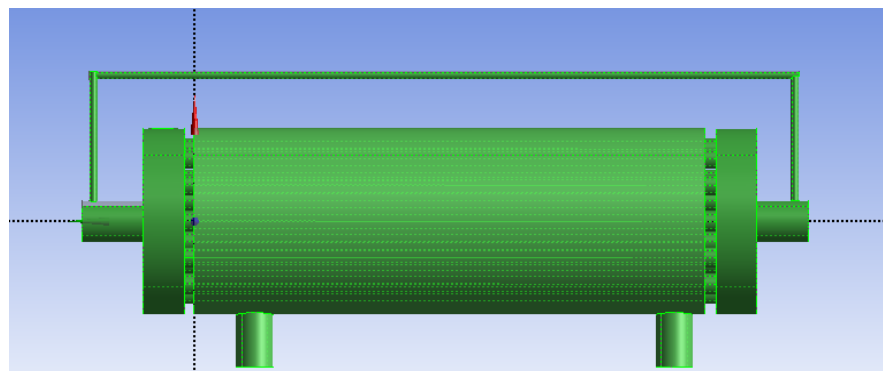


Figure 1: Shell and Tube Heat Exchanger ANSYS igs File with All Components

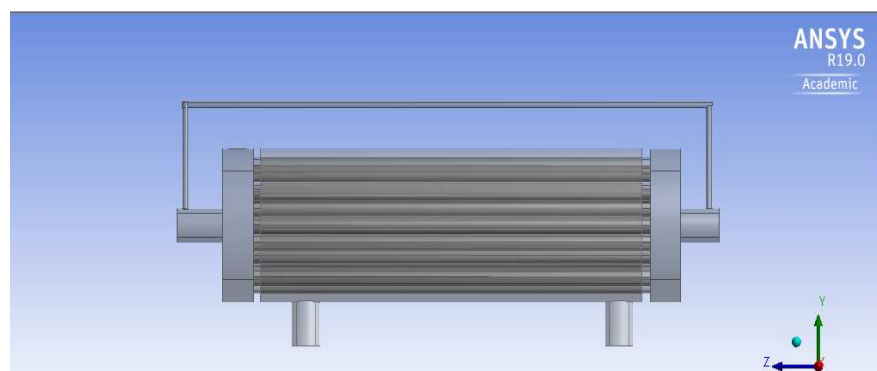


Figure: 2 Shell and Heat Exchanger igs File, Shell is Hidden for Visibility of Tubes

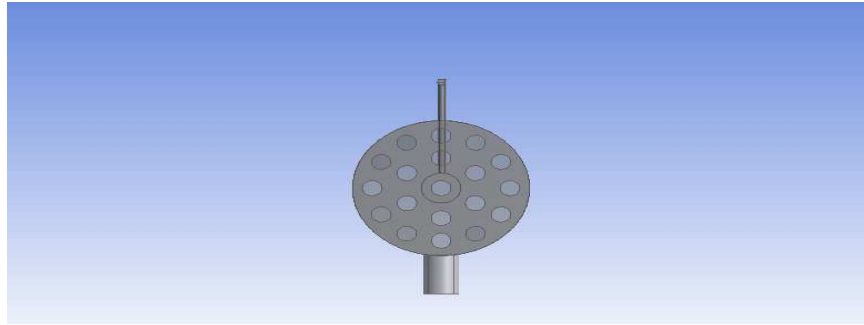


Figure 3: Shell and tube Heat Exchanger Side View

RECYCLING

The name “Recycling” reflects about the concept. Recycling of fluid means after completion of the process a portion of both the fluids pass through their respective outlets to outside of heat exchanger. The normal process won't consider whether the heat exchanging of fluids is performed properly or not. In the process of recycling, some amount of outlet side fluid is again added to inlet side fluid, which is added to their respective passing area before entering into the heat exchanger.

Recycling is divided into two types: 1. External recycling, 2. Internal recycling.

External Recycling

The tube side outlet fluid, say, at T_2 is mixed into tube side inlet, which is at, say, T_1 . In this process, the outlet side fluid temperature is less than inlet side temperature as heat is already transferred once during the earlier cycle. Through external tube (i. e. from outside of the system) fluid will be sent. When the outlet side fluid is sent to inlet side, as inlet side temperature is more than outlet side temperature, heat transfer takes place before the fluid entering into the respective heat exchanger, say, T_{21} .

So at that time, the mixed fluid, which is entering into the heat exchanger has a temperature below the temperature compared to when the same fluid is entering without recycling resulting in increased heat transfer.

Figure 4 depicts shell and tube heat exchanger with external tube (for recycling) in isometric view.

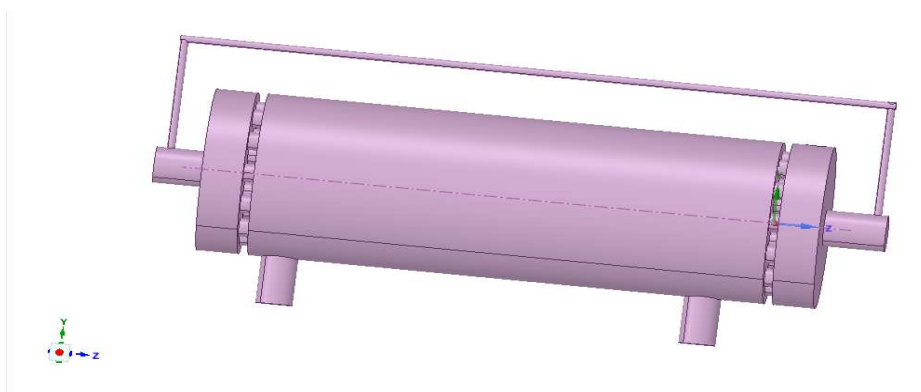


Figure 4: Shell and Tube Heat Exchanger in Isometric View

Internal Recycling

Internal recycling is similar to external recycling but that additional tube passes through the inner side of the heat exchanger, which results in higher heat transfer rate. However, this can't be done for a shell and tube heat exchanger because shell and tube heat exchanger already has its tubes inside the shell.

TEMPERATURE ANALYSIS

In the present investigation, different temperatures are considered for tube side fluid to simulate the temperatures. Before making the software to run the heat exchanger file, it has to undergo meshing. The accuracy of the results depends on meshing. Meshing allows all heat exchanger parts to share an equal amount of flow and obtain results accurately.

Figures 5 and 6 show meshed shell and tube heat exchanger with the external tube in isometric view and side view.

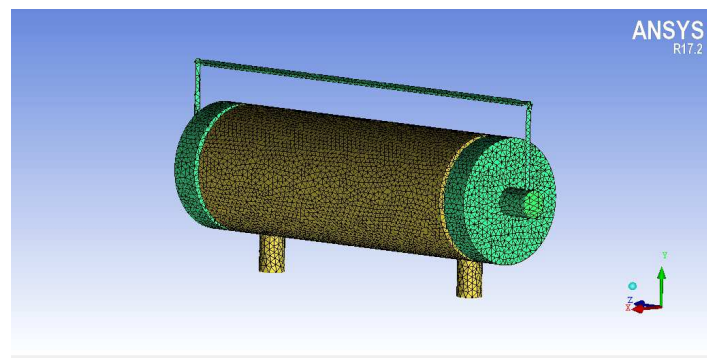


Figure 5: Shell and Tube Heat Exchanger representing with its Meshing in Isometric View

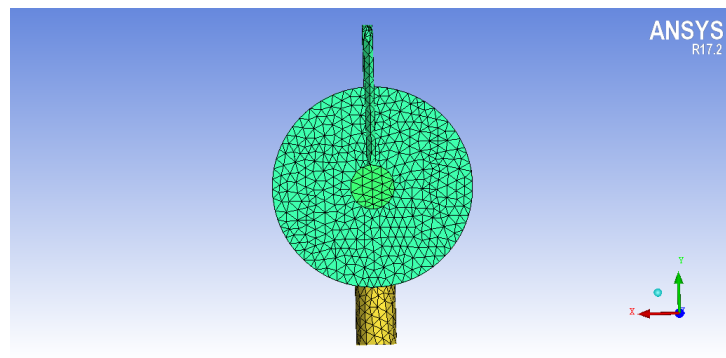


Figure 6: Side View of Meshed Shell and Tube Heat Exchanger

While doing analysis, different temperatures at both shell and tube sides are noted. Table 1 gives those temperatures:

Table 1: Representing the Temperatures used in Analysis

Tube Side Temperatures ($^{\circ}\text{C}$) (T_1)	Shell Side Temperature ($^{\circ}\text{C}$) (S_1)
50	25
60	25
70	25
80	25
90	25

Figures 7 and 8 indicate shell and tube heat exchanger with the external tube when temperature analysis is under simulation. This is a very important operation to obtain outputs.

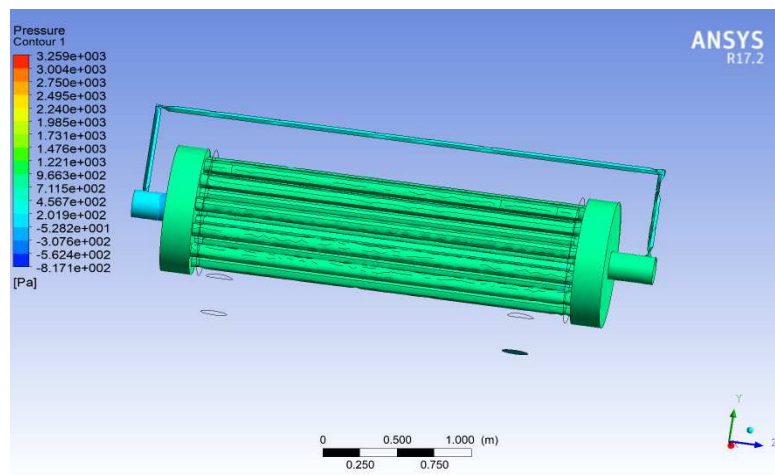


Figure 7: Heat Exchanger Tubes are Shown

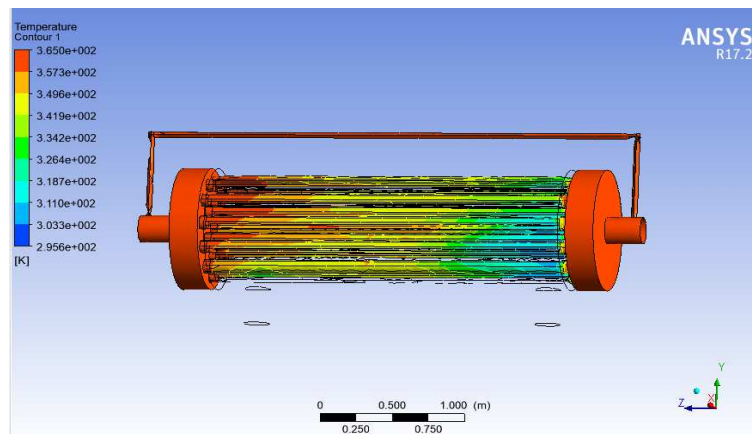


Figure 8: Representing the Heat Exchanger when the Analysis Pursuing in Fluent 19.0

After analyzing the problem with the above inputs, the results obtained are clearly showing the increase in heat exchanging rate.

Output Values of Normal Shell and Tube Heat Exchanger

Following values are obtained from the normal shell and tube heat exchanger without any type of external pipe added, i. e. no recycling process is done.

Table 2: Temperatures of Shell and Tube Heat Exchanger in $^{\circ}\text{C}$ without Recycling

Tube Inlet (T_1)	Tube Outlet (T_2)	Shell Inlet (S_1)	Shell Outlet (S_2)
50	49.7	25	25.3
60	59.5	25	25.8
70	69.1	25	26.4
80	78.6	25	27.1
90	88.5	25	27.9

Output Values of Shell and Tube Heat Exchanger with External Tube Placed for Different Flow Rates used while Recycling with External Tube

Following values are obtained with the external tube is in force. When outlet of the tube is connected to inlet of tube side, there will be a decrement in main fluid temperature before entering into the system so that additional heat transfer will be delivered. The following table provides the inputs given and the resulting outputs after external recycle done with a flow velocity of 1 kg/s.

Table 3: Results of Shell and Tube Heat Exchanger with External Recycling using 1 kg/s Flow through External Tube

Tube Inlet (T_1)	Tube Inlet Temp before Entering into Heat Exchanger after Flowing through External Tube (1 kg/s) (T_{21})	Tube Outlet with Recycle (T_3)	Shell Inlet (S_1)	Shell Outlet after Recycle (S_3)
50	49.667	49.6	25	25.8
60	59.1	58.9	25	26.3
70	68.9	68.6	25	26.9
80	78.45	77.9	25	27.3
90	88.3	87.2	25	28.1

The following table gives the output values after external recycle done with a flow velocity of 1.5 kg/s.

Table 4: Results of Shell and Tube Heat Exchanger with External Recycling using 1.5 kg/s Flow through External Tube

Tube Inlet (T_1)	Tube Inlet Temp before Entering into Heat Exchanger after Flowing through External Tube (1.5 kg/s) (T_{21})	Tube Outlet with Recycle (T_3)	Shell Inlet (S_1)	Shell Outlet after Recycle (S_3)
50	49.54	49.4	25	26.1
60	59.07	58.65	25	26.6
70	68.8	68.3	25	27.09
80	78.4	77.1	25	27.7
90	87.1	86.9	25	28.5

The following table summarizes the output values after external recycle done with a flow velocity of 2 kg/s.

Table 5: Results of Shell and Tube Heat Exchanger with External Recycling using 2 kg/s Flow through External Tube

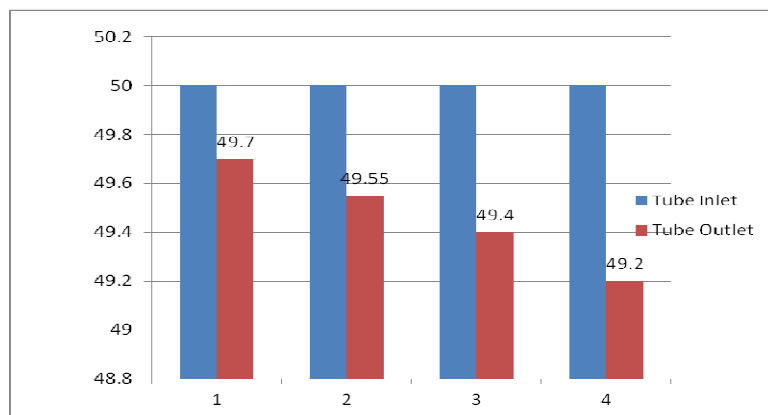
Tube Inlet (T_1)	Tube Inlet Temperature before Entering into Heat Exchanger after Flowing through External Tube (External Recycle Done) (2 kg/s) (T_{21})	Tube Outlet with Recycle (T_3)	Shell Inlet (S_1)	Shell Outlet after Recycle (S_3)
50	49.33	49.2	25	26.2
60	59.03	58.5	25	26.65
70	68.716	68.1	25	27.14
80	78.38	76.6	25	28.68
90	87.2	86.1	25	29.27

BAR CHARTS

The results are also plotted in the form of Bar charts. Bar Graphs indicating tube side heat transfer rate between 50°C to 90°C with normal heat exchanger and external tube added heat exchanger (i. e. Recycling process).

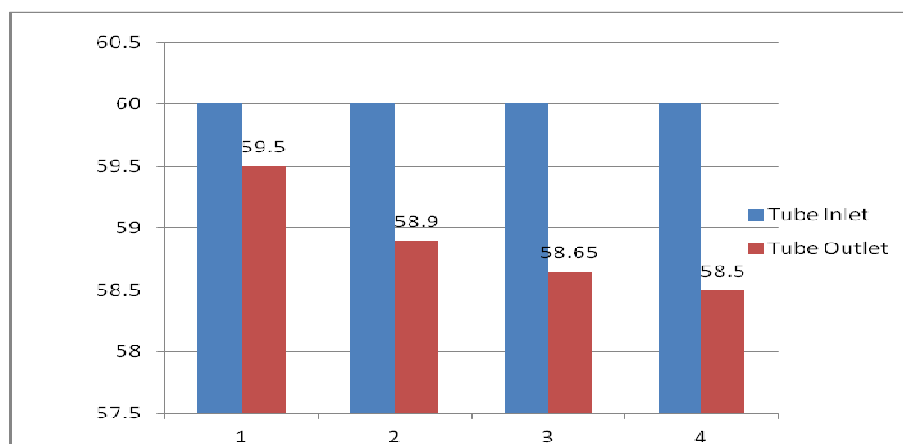
Note

- X-Axis indicating
 - Without Recycle (Normal Shell and Tube Heat Exchanger)
 - 1 kg/s external tube flow rate while recycling
 - 1.5 kg/s external tube flow rate while recycling
 - 2 kg/s external tube flow rate while recycling
- Y-Axis indicating tube side temperatures used in the analysis ($^{\circ}\text{C}$)
- Shell side temperature is kept constant at 25°C in the entire analysis
- Only tube side results are shown in bar graphs



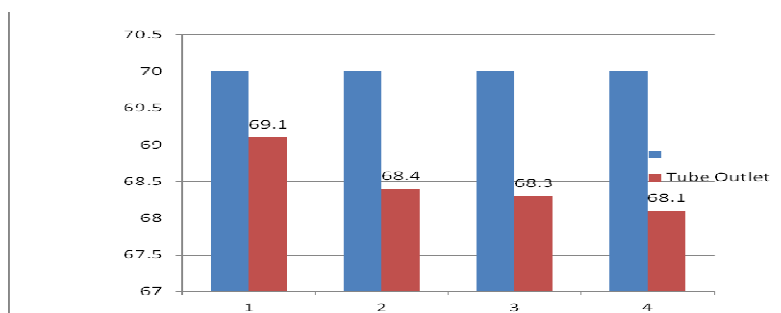
Bar Chart 1: Heat Transfer Taking Place with Tube Inlet Temperature at 50°C without (1) and with Recycling (2, 3 & 4)

As could be seen from the above Bar chart, the tube side outlet temperatures are clearly indicating improvement in heat transfer rate (by way of reduction in temperature).



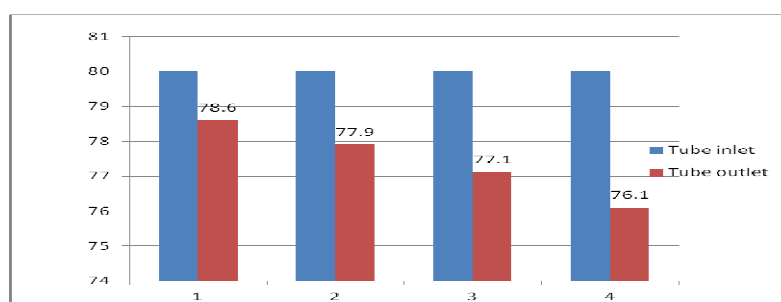
Bar Chart 2: Heat Transfer taking place with Tube Side Temperature at 60°C without (1) and with recycling (2, 3 & 4)

As could be seen from the above Bar chart, the tube side outlet temperatures are clearly indicating improvement in heat transfer rate (by way of reduction in temperature).



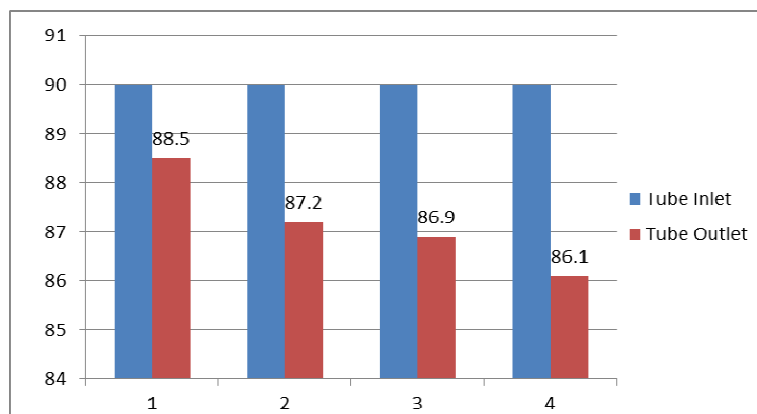
Bar Chart 3: Heat Transfer taking place with Tube Side Temperature at 70°C without (1) and with Recycling (2, 3 & 4)

As could be seen from the above Bar chart, the tube side outlet temperatures are clearly indicating improvement in heat transfer rate (by way of reduction in temperature).



Bar Chart 4: Heat Transfer taking place with Tube Side Temperature of 80°C without Recycling (1) and with Recycling (2, 3 & 4)

As could be seen from the above Bar chart, the tube side outlet temperatures are clearly indicating improvement in heat transfer rate (by way of reduction in temperature).



Bar Chart 5: Heat Transfer takes place with Tube Side Temperature at 90°C without (1) and with Recycling (2, 3 & 4)

As could be seen from the above Bar chart, the tube side outlet temperatures are clearly indicating improvement in heat transfer rate (by way of reduction in temperature).

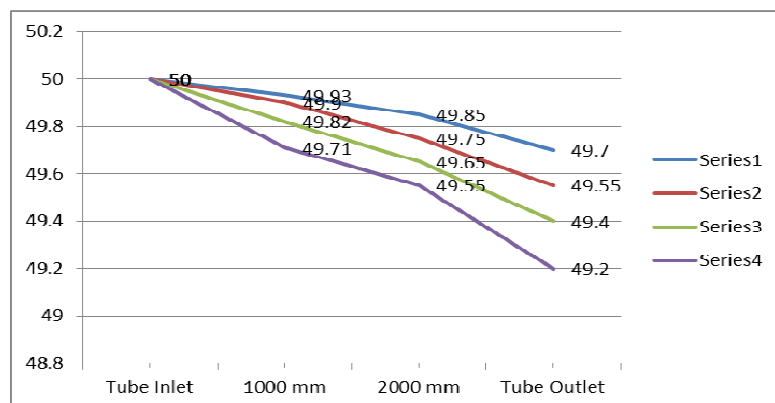
LINE GRAPHS

Normal line graphs showing the increase in heat transfer rate are plotted and presented. The four values in each line of the following graphs are indicating temperature outlets with and without recycling. The blue line on top indicates

the values obtained after simulating the shell and tube heat exchanger without recycling. The red line is obtained for simulating heat exchanger with recycling using 1 kg/s external tube flow velocity. The green line is obtained for 1.5 kg/s external tube flow rate. And the last violet line is obtained with recycle rate of 2 kg/s of external tube. Each line graph dealing with one tube inlet temperature. Heat transfer rate is increased from 0.3% to 1% for each recycling of different recycling flow rates. The line graphs plotted below clearly show that the output temperature of the normal heat exchanger is obtained much earlier in the heat exchanger with external recycling.

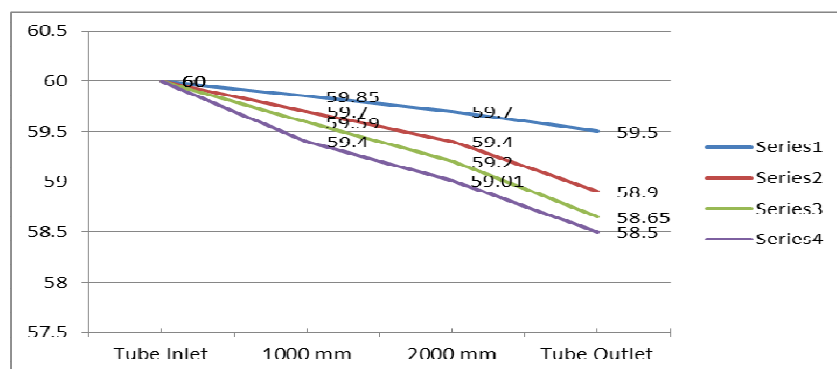
Note

- In X-Axis temperatures taken in the analysis are placed
- In Y-Axis length of tubes in a heat exchanger is placed
- Red line indicates tube side outlet temperatures without recycling applied.
- A blue line indicates tube side outlet temperatures when recycling applied with 1 kg/s flow rate in external tube
- The green line indicates tube side outlet temperatures when recycling applied with 1.5 kg/s flow rate in external tube
- Violet line indicates tube side outlet temperatures when recycling applied with 2 kg/s flow rate in the external tube.



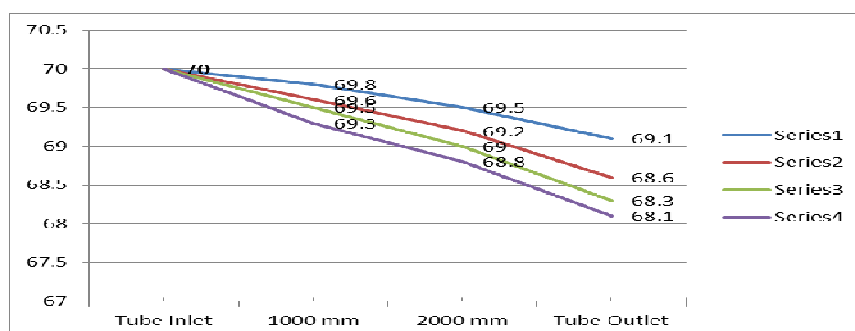
Graph 1: Indicating the Heat Transfer Rate of Heat Exchanger without and with Recycle at 50°C in All Three External Tube Flow Rates

Graph 1 shows the tube side outlet temperatures for an inlet temperature of 50°C with and without recycle. The outlet temperature of the heat exchanger with recycling is better (lower) compared to the normal heat exchanger (without recycling).



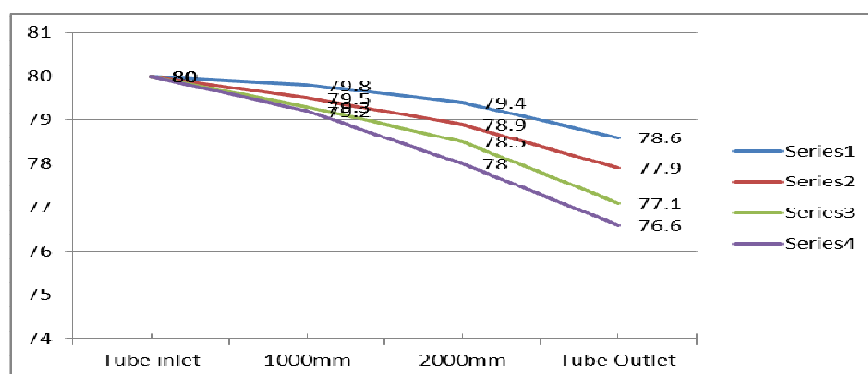
Graph 2: Indicating the Heat Transfer Rate of Heat Exchanger with and without Recycle at 60°C in All Three External Tube Flow Rates

Graph 2 shows the tube side outlet temperatures for an inlet temperature of 60°C with and without recycle. The outlet temperature of the heat exchanger with recycling is better (lower) compared to the normal heat exchanger (without recycling).



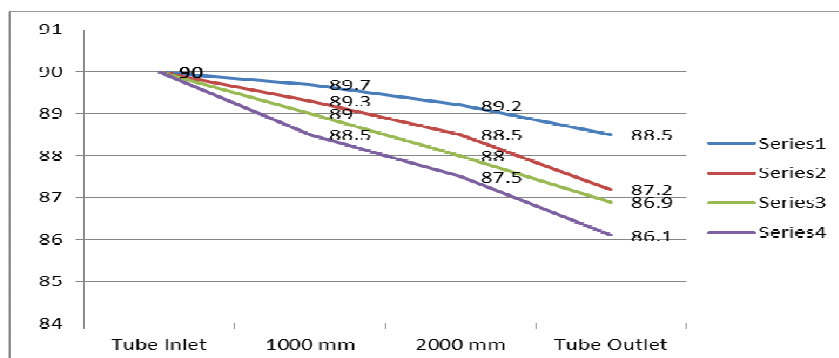
Graph 3: Indicating the Heat Transfer Rate of Heat Exchanger with and without Recycle at 70°C in All Three External Tube Flow Rates

Graph 3 shows the tube side outlet temperatures for an inlet temperature of 70°C with and without recycle. The outlet temperature of the heat exchanger with recycling is better (lower) compared to the normal heat exchanger (without recycling).



Graph 4: Indicating the Heat Transfer Rate of Heat Exchanger with and without Recycle at 80°C in All Three External Tube Flow Rates

Graph 4 shows the tube side outlet temperatures for an inlet temperature of 80°C with and without recycle. The outlet temperature of the heat exchanger with recycling is better (lower) compared to the normal heat exchanger (without recycling).



Graph 5: Indicating the Heat Transfer Rate of Heat Exchanger with and without Recycle at 90°C in All Three External Tube Flow Rates

Graph 5 shows the tube side outlet temperatures for an inlet temperature of 90°C with and without recycle. The outlet temperature of the heat exchanger with recycling is better (lower) compared to the normal heat exchanger (without recycling). The above graph shows the difference in heat transfer rate between with and without recycle. 88.5°C temperature is obtained at around 2000 mm with recycle, but without the recycling same temperature is obtained at the end of the process at 3000 mm. Here this recycling saves 1000 mm length from the heat exchanger. In industries, space is very important; with this process industries could get same output within lesser space.

RESULTS AND DISCUSSIONS

External recycling is applied to shell and tube heat exchanger for three flow rates, viz. 1 kg/s, 1.5 kg/s, and 2 kg/s. By using recycles the heat transfer rate is increased by about 1% for simple shell and tube heat exchanger. The increment is shown in bar charts and line graphs. By using recycles, higher heat transfer rate occurs between hot and cold fluids.

The inlet and outlet temperatures of tube side fluids are shown in the form of Bar charts. It shows a clear difference between heat transfer improvement without recycle and with recycling. Increase in external flow rate leads to higher heat transfer rate. Also, the recycling external flow rate should be small. High external tube flow rate affects the main hot fluid flow rate.

The heat exchange values at particular points in the heat exchanger from tube inlet to tube outlet are also plotted. They clearly show improvement in the heat transfer with recycling. The outlet temperature of the heat exchanger, which is attained with recycling, is higher than that without recycle. So the length of the heat exchanger could be trimmed by using recycling concept.

CONCLUSIONS

The present investigation reports that efficiency and heat transfer rate of heat exchangers can be increased by using recycling concept or alternatively, the length of the heat exchanger could be decreased to some extent, thereby reducing the space requirements.

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